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Research Article

Public preferences for edible invasive alien marine species - The Atlantic blue crab in southern Italy

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Abstract

Since 2014, the provision of the aquatic ecosystem services has been gradually affected due to the biological invasion of *Callinectes sapidus* (Rathbun, 1896, Crustacea, Decapoda, Portunidae), commonly known as Atlantic blue crab, across several lagoon-like locations in Italy. In addition, this serious aquatic invasive species, native of North American coasts, has already inflicted economic damage of about EUR 100 million to the Italian fishing and farming communities over the past year. To counter their severe and rapid spread, the Italian Government has encouraged the fishing communities to catch as many as possible and commercially exploit them for human consumption in an attempt to manage their expansion. Since there is an ongoing promotion for the consumption of blue crab by forging novel food businesses in Italy, this paper aims to predict the public preferences and their willingness to pay (WTP) towards this biological invader. For this purpose, a discrete choice experiment approach is used, by means of a multinomial logit model (MNL) and latent class model (LCM). The social field survey involves a representative sample of 440 valid respondents in Apulia Region, southern Italy. The descriptive statistics results reveal that 67.50% of the local citizens interviewed know about the blue crab invasion, while 29.09% of them have already consumed this seafood species. In addition, the MNL results show that the most appreciated attributes of the blue crabs by respondents are freshness and large size. Further, the LCM findings reveal two representative classes of Apulian consumers; the first group of citizens (70.9% of total respondents) expresses positive appreciation for consuming blue crabs, while the second group (29.1% of total respondents) is not willing to pay a premium price regarding this potential commercial activity. Furthermore, the econometric results show that the average value that Apulian's (i.e. those belonging to Class/Group I of respondents) WTP for blue crabs' consumption is about EUR 18 per kilogram. In this regard, this research has public and private implications and may reasonably promote the commercial exploitation of blue crabs, enhancing the reduction of its population density through human consumption as a promised management control strategy and forging a novel profitable business mainly for local small-scale artisanal fisheries.

Key words: Alien species consumption, aquatic ecosystem services, *Callinectes sapidus*, coastal biological invasions, discrete choice experiment, econometric analysis, social perception

Introduction

Human shipping activities provide wide-ranging economic benefits (Balzani et al. 2022), while also driving biological invaders outside their native range, potentially leading to biodiversity, social and economic losses (Cardone et al. 2022; Demetriou et al. 2023), undermining human well-being and inducing significant economic management costs in recipient communities (Kourantidou et al. 2021a). This is especially true for aquatic invasive species, which also present a serious potential food competitor to native community fish (Ogorelec et al. 2022), threatening the structure and stability of the marine ecosystems (DeRoy et al. 2022). Climate change, in terms of high temperatures and low precipitation, is also contributing to the impact on the taxonomic and functional diversity of marine species communities (van Deurs et al. 2021; Souza et al. 2023; Saifi et al. 2024). In this direction, the *Callinectes sapidus* (Rathbun, 1896, Crustacea, Decapoda, Portunidae), known as the Atlantic blue crab (Fig. 1a), an aquatic invasive species, native to North American coasts (Sabelli 2023), is a relevant case of this biological coastal invasion phenomenon and is considered amongst the most aggressive of the marine invasive groups (Swart et al. 2018). In the context of international trade, blue crabs have been introduced by commercial large vessels that use ballast water for weight adjustment, controlling buoyancy and stability. By pumping unfiltered water during their transoceanic crossing, these vessels can accidentally load invasive crustaceans, such *Callinectes sapidus* and then discharge them into a new non-infected seabed, such the Euro-Mediterranean Basin, at the end of their voyage, thus initiating the blue crab's invasion process (Nehring 2011). As such, the first observation of blue crab's species occurred in the French Atlantic coasts in 1900, in the Mediterranean Sea in the 50s, in Egypt at the end of the 19th century, in Italy (Apulia Region, southern Italy, Fig. 1b) in 2014 and in Tunisia (Gulf of Gabes, Tunisia's east cost in the Mediterranean Sea) in 2015 (Mancinelli et al. 2017). On the one hand, blue crabs are recognised as voracious biological invaders due to their: (*i*) omnivore and feeding flexibility (Johnson et al. 2014), (*ii*) exponential increase and various abundance across spatial and temporal aquatic systems and seasons (Mancinelli et al. 2017), (*iii*) rapid invasion in non-native habitats (Clavero et al. 2022), (iv) severe economic, social and environmental impacts (Marchessaux et al. 2023) and (*v*) strength of interactions with other marine species (Prado et al. 2024). On the other hand, these aquatic creatures are generally appreciated as healthy seafood species by consumers due to their high nutritional values (i.e. excellent source of proteins and minerals) and their organoleptic quality (Nanda et al. 2021) in terms of sweetness, tender meat, unique flavour and delicious taste. Against this background, there is increasing interest in assessing the benefits and costs of ecosystems services in real-world situations (Courtois et al. 2014).

In this sense, the reduction of its population through commercial exploitation for human consumption in Italy, as has already been developed in several countries, such as Egypt (Abdel-Razek et al. 2016), Greece (Kevrekidis et al. 2013), Turkey (Ayas and Ozogul 2011; Harlıoğlu et al. 2018), Tunisia (Ennouri et al. 2021) and USA (Sharov et al. 2003), is proposed as one of the best comprehensive management controls of this threat (Marchessaux et al. 2023). Similarly, this invasion may yield changes in the human well-being of Apulian fishermen and may be considered as a potential source of revenues, enhancing the livelihoods of local artisanal small-scale fisheries, as mentioned above and detailed in Fig. 2.

Figure 1. **a** an example of blue crabs catches in Lake Lesina – Lagoon – north of Apulia Region (southern Italy, Fig. 1b). The blue crab is an omnivore having: (*i*) an average life span in the wild from 1 to 3 years; (*ii*) a size of 4 inches (10 cm) long, 9 inches (23 cm) wide and (*iii*) a weight of 1 to 2 pounds (453 to 907 g) **b** the Italian geographical position of Lake Lesina. Fig. 1b also highlights of the hotspots (in red) where *Callinectes sapidus* has been observed in the study area. Source: Ludovica Nardelli (2023), co-author. Appendix 1 gives an overview of the marine fishing sector in Apulia Region, the study area.

Callinectes sapidus **invasion considered as a:**	
Biological threat, inducing negative impacts such as:	**Commercial interest, inducing positive impacts such as:**
❖ **Ecological losses in terms of:** • **Habitat modification** • **Biodiversity loss** • **Decrease of the quality of the marine ecosystem services** ❖ **Socio-economic losses for human activities in terms of:** • **Impacts on fisheries (i.e., damage to fishing nets, increased hard work; physical damage to fishermen; decrease of commercially shellfish revenues; degradation of the image of coasta lareas and products; decrease in people's welfare)** • **Impacts on tourism industry (i.e., decrease in tourism revenues; damage to coastal residents, fishing and aquaculture tourism and water-based recreation)** • **Impacts on catches (i.e., physical damage to fish; mortality of catches in the net; decrease of local species density)** • **Additional costs of private management & medical treatments**	❖ **Development of artisanal small-scale fisheries** ❖ **Industrialisation of blue crabs species** ❖ **Development of tourism activities: Integration of blue crabs on the restaurants menus** ❖ **Improvement of local food diet, in which the blue crabs present a high nutritional value** ❖ **Increase in local employement to manage/catch the blue crabs** ❖ **Increase in public & private management programs towards biological coastal invasions**

Figure 2. Overview of the impacts of *Callinectes sapidus*, based on the scientific paper of Marchessaux et al. (2023). In this regard, changes in marine ecosystem services and human well-being due to edible invasive alien marine species give rise to assess public's preferences about propensity purchase and willingness to pay a premium price for its consumption that would be considered as a promised sustainable control measure.

Meanwhile, not all invasive alien marine species can cause negative damage (Minasidis et al. 2023) and their perception may not be perceived similarly by all social public groups. Therefore, assessing the propensity purchase and willingness to pay a premium price for its consumption as a control measure constitutes a crucial component of the economic analysis of invasive species that is used when government choices are considered for controlling biological threats (Emerton and Howard 2008). Moreover, Apulian consumers as contributors may pay incremental charges towards this coastal biological invasion. Consequently, their preferences are crucial in the decision-making process to systematically manage such phenomena in terms of effectiveness and cost efficiency. Without this previous consideration, there is likely to be a risk of wasteful and imprudent resource allocation (Frem et al. 2021).

In this direction, this study focused on Apulia Region, south-eastern Italy (Fig. 1b) and was carried out to elicit consumers' preferences for Apulian blue crabs and to estimate their WTP, enhancing the purchase and, consequently, the consumption of blue crabs in their regional markets. Additionally, this research identifies consumers market segments through the: (*i*) specific attributes (see section Methodology) of this marine invasive species, (*ii*) propensity and attitudes of purchase, as well as (*iii*) socio-economic and demographic characteristics of respondents, within an econometric analysis of biotic invasive framework. Specifically, this study addressed three interrelated research questions: (i) what are the consumers' profiles for Apulian blue crabs; (ii) what are their preferences for this marine invasive species and (iii) what are their WTP for consuming Atlantic blue crab?

However, to address these research questions, we opted for an econometric Discrete Choice Experiment (DCE) approach (Petrontino et al. 2022, 2023a, 2023b), to provide insights into biological invasion policy decision-making. In this regard, the originality of the present paper is dual. First, to the best of our knowledge, this is the first econometric and social study on one of the most recent coastal biological invaders in Italy, where the need for reduction options management is of primary governance importance. In this sense, the Italian Government has recently allocated EUR 2.9 million (MASAF 2023, see Appendix 2) to tackle the aggressive invasion of the Atlantic blue crabs, which are threatening the fishing industry, mainly relating to clams, mussels and oysters[1], in Italy. These seafood attributes sustain the Apulia economy and are served in their many traditional dishes. Second, the present paper enhances the peer-reviewed literature that uses DCE to elicit social perception regarding the coastal invasion by non-indigenous species. In recent years, there have been a few studies that have used DCE to give insights into invasive species management. For example, Bougherara et al. (2022) estimated spatially differentiated preferences for the management of primrose willow (*Ludwigia grandiflora*), an invasive weed spreading in a French regional park. They use a DCE to estimate people's WTP to control the invasion of this

1 Interspecific relationships (predation: predator-prey, trophic competition) play a crucial role in shaping marine ecosystems. With respect to predation, the latter involves one species (the predator, here: the blue crab) consuming another (the prey, here: e.g. clams, mussels and oysters), affecting their population dynamics and community structure, regulating prey populations, influencing their abundance patterns and shaping marine community dynamics. Regarding the trophic competition, the latter occurs when species compete for the same resources (i.e. food, habitat). As such, the blue crab may compete with other species (i.e. other crabs, fish) for similar prey, affecting habitat selection and ecological niches.

species in different areas of the regional park. Frem et al. (2021) used a DCE in Italy to map residents' preferences heterogeneity and their WTP to regenerate the olive landscape that has been severely affected by *Xylella fastidiosa*, an invasive bacterium. Bekele et al. (2018) used a DCE to assess the economic value of dry land ecosystem services that had been degenerated by the invasive *Prosopis spp.*, in Ethiopia and Kenya. Malpica-Cruz et al. (2017) conducted a DCE to assess the potential economic impacts of the Lionfish invasion in the Mexican Caribbean, in which lionfish-control fees were acceptable to some, but not to all recreational users. Additionally, Zeilinger et al. (2014) address the importance of consumer feeding preference amongst resource choices, inducing critical implications for ecological risk assessment and invasion biology. Finally, Rai and Scarbourgh (2013) designed a DCE to estimate WTP to mitigate damages caused by invasive plant species in a rural community of Nepal. Compared to the number of DCE studies on management of invasive species, there have been more DCE studies on the consumption of seafood species using a DCE approach. For example, Sigurdsson et al. (2023) investigated how different combinations of signals (i.e. certificates/tags; health/sustainability) impact consumers' choice and WTP for fish fillets. Zheng et al. (2023) estimated United States consumers' willingness to pay for genetically modified salmon and examined heterogeneity in preferences across levels of consumer perceptions, knowledge and attitudes. Rodriguez-Salvador and Dopico (2023) investigated consumers' preferences for the origin and traceability of fish products. Risius et al. (2019) elicited target groups for fish from sustainable aquaculture and their preferences for different countries of origin. These previous studies are based on native fish or seafood products rather than on alien aquatic species. In this respect, the results of this research triggered private and public implications, forging a potential novel profitable fishery business and raising social awareness with respect to an edible marine invasive species like *Callinectes sapidus*.

Methods

In this paper, we implemented a DCE approach that is used in valuation of marine ecosystem services and marine food products, but less so for edible alien marine species. Thus, our paper contributes to the scarce literature on revealing people's preferences for edible invasive alien marine species and the socio-economic characteristics and other factors that drive their WTP to consume such species. In line with similar studies, this approach involved five major components, such as: (*i*) Identification, description of attributes and designation of their levels, (*ii*) Development of an experimental design and construction of choice set, (*iii*) development of a social-choice survey questionnaire and data collection, (i*v*) Econometric estimation models regarding the measurement of consumers' preferences by the means of a Multinomial Logit Model (MNL), development of cluster profiles using Latent Classes Model (LCM) and estimation of WTP in each of these cluster profiles, as well as (*v*) Interpretation of results for policy analysis or decision support. The WTP estimates of consumers reflected the hypothetical change in the utility (i.e. sense of satisfaction) or acceptability or unacceptability (Börger et al. 2014; Malpica-Cruz et al. 2017) associated with the consumption of invasive alien species, such *Callinectes sapidus* as a contribution to its management.

Identification of attributes and designation of levels

As a first component of the DCE, we first based the identification of attributes and levels on the empirical literature related to consumer purchasing behaviour towards fish and seafood products (Carlucci et al. 2015), including country of origin, product methods, preserving methods, product innovation, packaging, eco-labelling etc. Hence, we used an approach involving a focus group of experts to select the considered attributes and design their correspondent levels. From an invasion management perspective, understanding consumer preferences for preservation methods can help to elaborate value-added products within a supply chain where, where the cold chain or the direct refrigeration of freshly caught products is guaranteed. Consequently, it may have implications for those directly involved in fishing and preserving the product before placing it on the market to more effectively and, at the same time, sustainably manage the alien species. Similarly, the place of purchase may be of interest for the same reasons that may prompt different actors in the distribution chain to take an interest in blue crab management, including through awareness-raising campaigns. Subsequently, we retained six characteristics with three levels each as illustrated in Table 1.

The first category included three levels of seafood species (i.e. blue crab, spider crab and pink shrimp). The selection between these species might help to make a comparison between invader and non-invader common marine seafood attributes. In other words, we looked to compare the blue crab with two products that were

Table 1. Attributes and levels with symbols or pictograms selected to explore the hypothetical social perception and willingness to pay towards *Callinectes sapidus* invasion in Apulia Region.

		Level 1	Level 2	Level 3
Attributes	seafood species	Blue crab	Spider crab	Pink shrimp
	Preserving method	Fresh/Chilled	Frozen	Canned
	Size	Small	Medium	Large
	Fishing origin	Italy	Apulia region	Abroad
	Place of purchase	Fishermen or Direct purchase	Fishing shops	Supermarkets or Hypermarkets
	Price	EUR 10 per 1 kg	EUR 17 per 1 kg	EUR 23 per 1 kg

Source: our elaboration.

close to it in terms of recognisability (i.e. shrimp as a common consumed shellfish and spider crab as a similar species already known by most Italian consumers). The second category involved three levels of preserving/storage methods (i.e. fresh/chilled, frozen and canned) for each designated seafood species. The preference between these preserving/storage methods might enhance relevance for fish stakeholders marketing several seafood products. The third category concerned the three levels of sizes (i.e. small, medium and large) for each identified seafood species. The selection between these sizes for each involved seafood species might address the preferences of Apulia consumers towards their most favourite size of marine fish species. The fourth category involved three levels for fishing/capture origin (i.e. Apulia, Italy and abroad), for each identified seafood species. The choice between these fishing origins might highlight which origin will be the main influencing preference for Apulia consumers for the concerned seafood species. The fifth category entailed three types of location for the purchase of the three seafood species (i.e. fishermen/direct purchase, fish shops and supermarkets/hypermarkets). The decision between these places for purchase might indicate which location might be considered as a driver or a barrier for the consumption of the concerned seafood species. The last attribute was related to the premium price that Apulian consumers would pay for their consumption of 1 kg of each considered seafood species (i.e. EUR 10, EUR 17 and EUR 23 per kg versus the status quo or EUR 0). We based this range of prices on a price survey on the Italian goods exchange system. Hence, this set of selling prices was considered to make the hypothetical market more compatible with prices that respondents see daily in stores. Furthermore, this category was considered as a discrete variable in the DCE, leading to estimate the consumers' willingness to pay for the consumption of blue crabs and to assess the monetary trade-offs that consumers make for each category and level considered in this study. We also illustrated all attributes by symbols or pictograms, supporting the respondents in their choice process (De Ayala et al. 2012) or providing a stimulus in which they might easily select a choice set (Zoderer et al. 2015).

Development of an experimental design and construction of choice sets

The experimental design followed a standardised procedure of conducting a pilot survey. This served to set up preliminary coefficients for the final experimental design and, based on the sign obtained in the respective levels, alternatives with implausible combinations were eliminated. Examples include alternatives that simultaneously contained very low prices with levels of the other attributes presumably leading to increased utility; or, conversely, high prices with levels of the other attributes presumably leading to disutility. After selecting the attributes and their levels (Table 1), we employed a full factorial experimental design, generating a high number of combinations 729 (3^6) and making it logistically unfeasible and impractical to administer all this quantum of choice sets to one respondent. Hence, we opted for a D-efficient fractional factorial design (Bush 2013) with an efficiency score of 0.85, using the code of package AlgDesign on R (Suppl. material 1). To prevent complexity, minimise confusion, survey costs and cognitive fatigue for respondents during the survey (Frem et al. 2021), as well as to improve efficiency (Zheng et al. 2023), the set of 60 scenarios were distributed into three blocks including five choice sets (i.e. known as "Options") each. In each choice set, we included four options. In this line, having three instead of one or two choice

options, in addition to the status quo, may also have positive implications, such as greater realism. However, including too many options may lead to respondent fatigue and potential uncertainty in preferences as stressed above. Consequently, we found that using three options was acceptable, given the extensive experimental design in terms of the large number of attributes and levels. As such, by offering three distinct options, the choice sets more closely reflect the real-world scenarios that participants may face when they make decisions about the topic being studied. Fig. 3 illustrates an example of a choice set used in our DCE approach. Each respondent had the opportunity to select one option amongst the four hypothetical options (A, B, C and D as an opt-out option), leading to a maximisation of his/her total utility for the consumption of blue crabs, assuming that this utility was a function of a selection in seafood species attributes and other determinants (i.e. size, place of purchase, fishing origin and price as a budget constraint).

Development of a social-choice survey questionnaire and data collection

We developed a structured questionnaire (Suppl. material 2) for data collection between May and October 2023 in Apulia Region. We tested the questionnaire with a sample size of 25 respondents, randomly selected from Apulia residents, taking into consideration their age and gender. The aim of this pilot survey was to test the effectiveness of the levels for each attribute, eliminate all irrelevant questions, estimate the time needed for face-to-face interviews and to guarantee that respondents fully understood the questionnaire. The language of the questionnaire was Italian and the survey was limited to Apulia residents.

The questionnaire was divided into three sections. The first section concerned the purchasing habits and propensities of Apulia citizens. This section included attitudinal questions dealing with individuals' general attitudes towards the purchase habits and propensities of food, fish products/seafood and their knowledge and consumption of the blue crabs, along with 13 questions, such as: "Do you personally take care of food purchasing for your family? (i.e. Yes; No) (Q1); How often do you shop for food? (i.e. once a day; more than once a week; once a week; more than

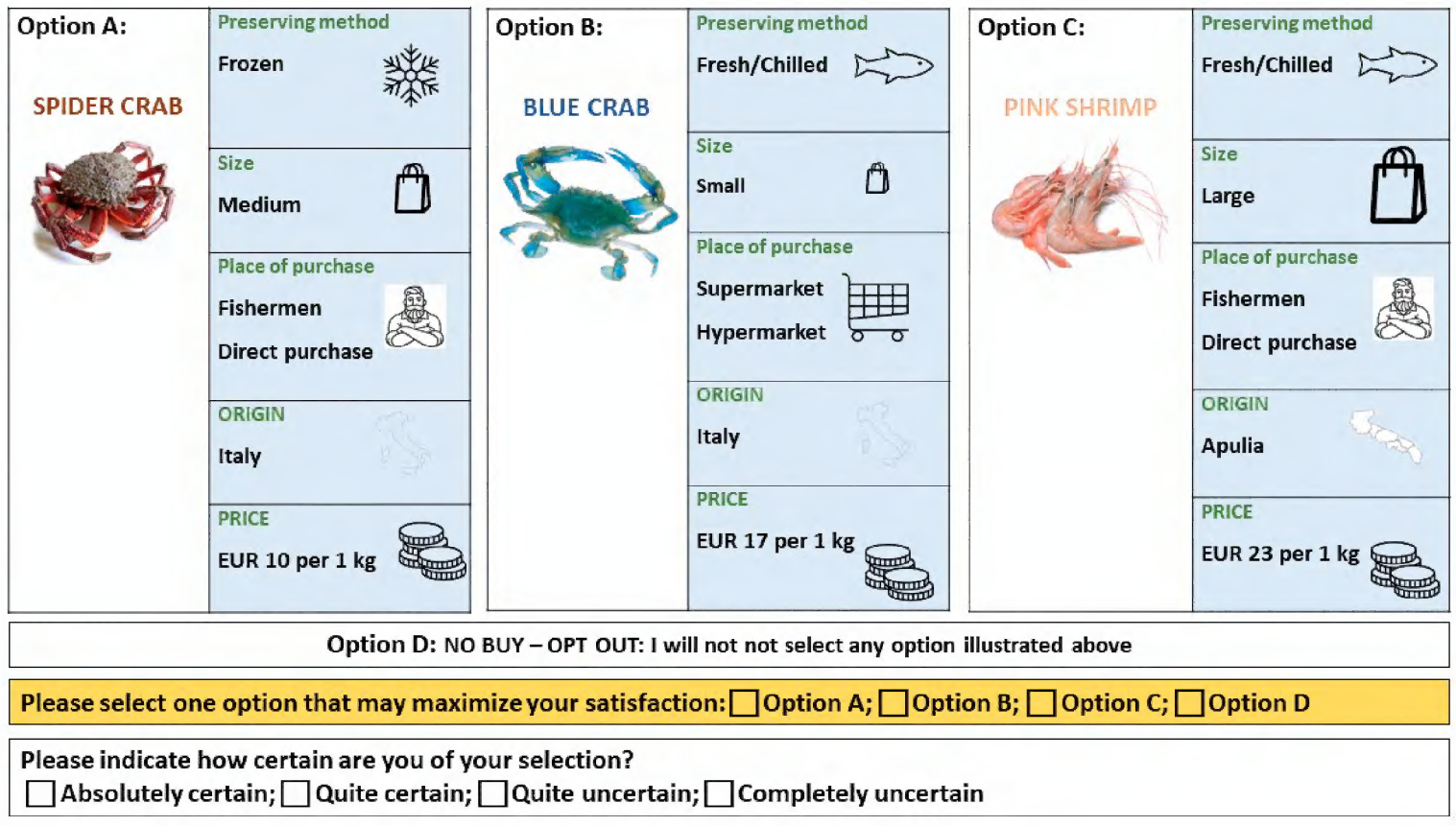

Figure 3. Example of a choice set used in our Discrete Choice Experimental (DCE) approach.

once a month; once a month; less than once a month; never) (Q2); Are you allergic to shellfish? (i.e. Yes; No) (Q3); How often do you consume shellfish? (i.e. always; often; sometimes; rarely; never) (Q4); Where do you usually buy products such as shellfish or related fish products? (i.e. direct sales (fisherman); fish shops; supermarkets; hypermarkets and shopping malls; other) (Q5); When buying seafood products, how much attention (i.e. not at all; little; quite a lot; a lot; very much) do you pay to the following characteristics? (i.e. place of purchase; commercial seafood species; origin of the product; price) (Q6); Do you know about the blue crab (i.e. Yes; No) (Q7); Have you ever consumed it? (i.e. Yes; No) (Q8); If you have never consumed it, can you give a reason? (Q9); How often do you buy blue crab? (i.e. always; often; sometimes; rarely; never) (Q10); Where did you buy it? (it is possible to select more than one answer) (i.e. direct sales (fisherman); local fisheries markets; supermarkets; hypermarkets; other) (Q11); Where did you most commonly consume it? (i.e. restaurant; events; home; other) (Q12); On a scale of 1 to 10, report your product satisfaction index about the consumption of blue crab (Q13).

At the end of this section, interviewees were informed about the current invasion of blue crab in Italy and its negative (i.e. a biological threat impacting the provision of ecosystem services and inducing socio-economic losses for human activities) and positive (i.e. potential source of revenues) implications on the fishery sector in Apulia. Two relevant images on blue crabs supported this section. The second section concerned the preferences of Apulia citizens for the consumption of blue crabs. In this section, we asked the respondent to make choices as described above (Fig. 3). We provided here five purchase simulations (i.e. choice sets) where the respondent could choose between three options (options A, B and C) which differ in the selected attributes and levels (Table 1). In addition to the three available purchase options, there was a no-purchase option (option D or opt-out) that he/she could choose if none of the three options offered satisfied him/her. At the end of each choice set, respondents were asked about their choice certainty, using a scale from 1 (absolutely uncertain) to 5 (absolutely certain) as depicted in Table 2, in which the overall mean of all respondents was equal to 3.83, indicating

Table 2. Respondents' certainty level of their choice using a scale from 1 (absolutely uncertain) to 5 (absolutely certain).

Choice set N°	Option N°	Mean	Std. Deviation	Min	Max
1	1	3.79	0.679	2	5
1	2	3.85	0.762	2	5
1	3	3.95	0.571	2	5
2	1	3.73	0.741	2	5
2	2	3.83	0.757	2	5
2	3	3.86	0.587	2	5
3	1	3.79	0.690	2	5
3	2	3.67	0.757	2	5
3	3	3.87	0.527	3	5
4	1	3.80	0.622	2	5
4	2	3.89	0.596	2	5
4	3	3.97	0.450	3	5
5	1	3.76	0.606	2	5
5	2	3.93	0.663	2	5
5	3	3.90	0.520	3	5

Table 3. Sample of Apulian participants field social survey used in our Discrete Choice Experiment.

	Year	Male	Female	Total		Year	Male	Female	Total
Population	Number (Apulia Region)				**Sample**	Number (Apulia Region)			
	18–44	606,237	587,116	1,193,353		18–44	63	68	131
	45–64	576,840	609,472	1,186,312		45–64	73	86	159
	≥ 65	413,081	517,356	930,437		≥ 65	71	79	150
	Total	1,596,158	1,713,944	3,310,102		**Total**	**207**	**233**	**440**
	In % (Apulia Region)					**In % (Apulia Region)**			
	Year	Male	Female	Total		Year	Male	Female	Total
	18–44	38%	34%	36%		18–44	30%	29%	30%
	45–64	36%	36%	36%		45–64	35%	37%	36%
	≥ 65	26%	30%	28%		≥ 65	34%	34%	34%

Source: Our elaboration, based on Istituto Nazionale di Statistica - ISTAT 2023.

an overall "enough certainty" of their choices. The third section aimed to collect data about the key socio-economic characteristics (i.e. gender, age, residence, civil status, family composition, level of education, work position, work sector and annual household income) that could contribute to their decision process.

The final survey involved 440 respondents in the study area, considering the Apulia population age and gender distribution, in which the sample was in a similar range to the main statistics of Apulia population (Istituto Nazionale di Statistica - ISTAT 2023) as reported in Table 3. For this purpose, we interviewed by block at least 60 respondents randomly distributed between the sexes (at least 30 females and 30 males) and ages (at least 25 males and females for each of the following age classes: 18 to 44, 45 to 64 and greater than 65 years old). For the statistical and econometric analysis, we only retained the respondents who declared that they were the main person responsible for shopping for food for household consumption.

Econometric estimation models: MNL and LCM

The DCE approach is based on the random utility maximisation framework and the theory of product attribute values (Lancaster 1966), in which a consumer's perception utility ("*U*") of terrestrial, marine and aquatic ecosystems or seafood products, such blue crabs, is generated from their attributes. The consumers' utility ("*U*") consists of deterministic (observable) and probabilistic (non-observable) components (Louviere et al. 2000). Using this theoretical foundation, we assumed that each attribute included in this study constituted one component of the blue crabs' utility which can be expressed as follows:

$$Uni = V_{ni} + \varepsilon_{ni} \quad \text{(Eq. 1)}$$

where: "*n*" is the users (i.e. respondents/consumers), "*i*" is the alternatives (choice sets, Fig. 3), "V_{ni}" is a function of observable attributes of the blue crabs, known as the deterministic component of "U" and "ε_{ni}" is a function of the non-observable characteristics of the blue crab's seafood product and respondent-level variation in unknown perceptions, preferences or attitudes considered as the stochastic part of "U" and treated as random error.

In line with similar studies, we also assumed an additive utility function linear of the observed attributes levels (Table 1). Based on this, *"Uni"* becomes:

$$U_{ni} = \alpha + \beta_1 x_{1n} + \beta_2 x_{2n} + \ldots + \beta_m x_{mni} + \varepsilon_{ni} \quad \text{(Eq. 2)}$$

where: "α" is a constant term; "x_{ni}" are the attributes of the alternatives ("*i*") for each respondent ("*n*") and "β" are the coefficients of the attributes of the options; "β" also reveals the preference weight for each attribute level, as well as trade-off monetary values; "β" represents the importance of the attribute level to the utility function that respondents/consumers give to an option.

When dealing with two or more options, the respondent will thus select the option associated with the highest utility (i.e. benefit or satisfaction). Thus, the probability that the n^{th} respondent chooses the i^{th} option from a choice set becomes:

$$P_{ni} = \text{Prob}(U_{ni} > U_{nj})\ \forall j \neq i = \text{Prob}(V_{ni} + \varepsilon_{ni} > V_{ni} + \varepsilon_{ni}) = \forall j \neq i = \text{Prob}(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj})\ \forall j \neq i \quad \text{(Eq. 3)}$$

To estimate "β" and their corresponding standard errors for each level of the six selected attributes (Table 1), we initially used the Multinomial Logit Model (MNL) which provided the basis for the analysis of DCE as innovated by McFadden (1974) for exploring choice behaviour in relation to the elements that describe the option. However, MNL has two limitations. First, the equal measurement of utility and the assumption of preference homogeneity amongst all respondents. In other words, MNL captures only the mean of preferences across the studied population. To counter these limitations, Random Parameters Model (RPL, known also as Mixed Logit Model) or LCM are used to account for and identify heterogeneity in respondents' choice preferences. RPL assumes that each respondent can have his/her own unique set of parameters, whereas LCM assumes that the studied population is divided into a finite number of classes or segments, each with their own set of parameters. Lastly, RPL offers a more nuanced view of individual-level variation, whereas LCM provides a more straightforward interpretation by identifying distinct groups (Vermunt 2003). Consequently and based on the specific needs of this research, we opted for the LCM because it can segment consumers into classes, based on their choice patterns. We assumed that interviewed consumers were heterogeneous in their attributes and preferences towards the consumption of blue crabs, that may differ according to some socio-economics characteristics and habits, as well as propensity for purchase and that blue crabs control fees might vary between consumers, leading to the adoption of targeted public communication and information at a specific group that will more likely induce a greater management impact towards the concerned biological invader rather more broadly than the communication policy (Malpica-Cruz et al. 2017). In this sense, the probability that a respondent will choose an alternative *i* is a function that includes the attribute levels of alternative *i* and the attribute levels of all other alternatives presented in Table 2 and becomes as follows:

$$Prob(choice = i) = \frac{exp^{V(\beta, Xi)}}{\sum_j exp^{V(\beta, Xj)}} \quad \text{(Eq. 4)}$$

where: $V(\beta, x_i)$ is the observed component of the utility function for alternative *i* and *j* is a set of alternatives.

Regarding the LCM, this model assumes that the studied population is divided into different unobserved/latent classes with regards to the attributes and levels and disentangles the probabilistic presence of any discontinuity in the heterogeneity of respondents, thus enabling them to cluster into homogeneous classes or segments, so that preferences are identical within the segment, but differ between them. As such, the LCM offers the opportunity to identify population heterogeneity and better understand the target respondents, leading to appropriate management interventions directed towards encouraging consumption of blue crab by particular groups of consumers.

In this direction, we applied LCM as a statistical clustering procedure (Weller et al. 2020) with two selected subclasses of respondents within the sample, relying on rigorous statistical tests (He and Fan 2019) and assuring the best representation of the target blue crabs consumer's market. For this purpose, we implemented a model fit statistics information criterion (Table 4), in which the most optimum fit improvement (i.e. optimum number of classes) is determined by the following criteria: maximum log-likelihood (IC), minimum Bayesian Information Criteria (BIC) and minimum adjusted Akaike Information Criteria (AIC), indicating the greatest amount of variation and using the fewest possible independent variables (Emiliano et al. 2014; Petrontino et al. 2022). As such, we applied these criteria to several classes of our respondents to select a reasonable number of clusters/groups with a good assurance regarding the stability, sensitivity and specificity of data as depicted in Table 3. Furthermore, the choice probability (Eq. 4) within a class q becomes as follows:

$$Prob(choice = i/\beta q) = \frac{exp^{V(\beta q, Xi)}}{\sum_{j} exp^{V(\beta q, Xj)}} \quad \text{(Eq. 5)}$$

With respect to WTP, we estimated the WTP that reflected the average price a respondent would pay for blue crabs' consumption for each of the two selected classes or groups of respondents (Nylund-Gibson and Hart 2014). We also performed a Wald procedure according to the Krinsky-Robb method, used with 500 draws. In this regard, we estimated the WTP by using the following equation:

$$WTPk = -\frac{E(\beta k)}{\beta(price)} \quad \text{(Eq. 6)}$$

where k_s are the attributes, WTP_k is the expected WTP for k, $E(\beta_k)$ is the estimate of the coefficient for attribute k and β(price) is the price coefficient.

Table 4. Selecting a class solution: Model fit statistics information criteria.

	Multinomial Logit	**2-Class**	**3-Class**	**4-Class**	**5-Class**	**6-Class**
Log-likelihood	-2050	-1989	-1948	-1920	-1898	-1886
Adjusted Akaike Information Criteria (AIC)	4124	4028	3972	3942	3924	3926
AIC/N	2.27	2.22	2.19	2.17	2.16	2.16
Bayesian Information Criteria (BIC)	4190.046	4165.596	4181.146	4222.696	4276.246	4349.796
Adj BIC	4190.084	4165.753	4181.504	4223.34	4277.259	4351.265
Average classes probabilities	100%	29.1%	9.1%	27.7%	36.1%	35.7%
		70.9%	26.5%	40.3%	35.1%	2.1%
			64.4%	22.6%	9.9%	9.7%
				9.4%	11.4%	16.1%
					7.5%	29.6%
						6.8%

Results

Statistical description of respondents

This section includes basic statistical results from the first and third sections of the questionnaire (Suppl. material 1), addressing the purchasing habits and propensities of Apulia residents towards fish products, their knowledge of the blue crabs, as well as their socio-economic characteristics. In this direction, Table 5 reveals that most respondents (82.5%) were personally in charge of food purchase more than once a month, while 2% of them had a shellfish allergy. A total of 57% of the participants in this social survey purchased seafood products at the fish shops, followed by supermarkets (20%), while 8% of them purchased directly from fishermen. Further, the price of seafood products was the most determining factor in their purchase decision, followed in succession by the preservation method, the place of purchase, the origin of fishing and the type of the seafood species. Regarding their knowledge of blue crabs, 67.50% of them were familiar with this product, while 29.09% of them had already consumed it.

In addition, 43.64% of them confirmed their ignorance about this seafood category as a key reason for non-consumption, while a few of them (9.32%) declared their difficulty in finding this product on the local fish market as a reason of non-consumption. Regarding their socio-economic profiles, on average, respondents were middle-aged (53.7 years old), female (53%) and widely distributed amongst their levels of education (primary school: 2%, secondary school: 22%, high school: 38%, university: 37%). The average length of the studies undertaken by the respondents was 13.6 years, while the average family size was nearly three members. In terms of the total annual gross family income, it was distributed as follows: 23.6% (less than EUR 25,000), 55.5% between EUR 25,000 and 50,000) and 20.9% (greater than EUR 50,000).

Econometric estimates of multinomial logit model (MNL) and latent class model (LCM)

The MNL estimates are reported in Table 6 and revealed that many coefficients of the concerned attributes ("seafood species – blue crab and spider crab; preserving method – canned; size – small; fishing origin – abroad") presented negative signs for the price and were highly significant at the notable level of 1%. On the contrary, the MNL findings showed that the opt-out coefficient ("no purchase" or option D) was equal to -0.63 and highly significant, indicating that the Apulian consumers would opt to purchase seafood species products. However, this econometric model only allowed us to elicit the mean preference contribution and might hide the individual variations of preferences amongst the samples, which might present different preferences as addressed below by the LCM model. In addition, Table 5 also revealed that the later model achieved better values in terms of the log-likelihood function AIC and BIC compared to the MNL model. With respect to the later model, the sample was divided into two classes of Apulian consumers, based on their perceptions and expectations towards non-indigenous aquatic species. According to the iteration performed for different number of classes, AIC improves as the classes increase, but it led to an excessive complication of the model. Therefore, BIC was used as a discriminant in the choice of the classes. Regarding class 1, Table 6, in coherence with the MNL results, depicted also negative signs and high statistical significance at the 1% level for the concerned attributes, implying a high level of influence on

Table 5. A summary of all the descriptive statistics of the sample.

Variable description	Category	Mean/%	SD	Min	Max
Are you personally in charge of food purchases?	Yes	82.5%			
Frequency of food purchase	1: Once a day; 2: More than once a week; 3: Once a week; 4: More than once a month; 5: Once a month; 6: Less than once a month; 7: Never	5.57	1.15	2	7
Do you have a shellfish allergy?	Yes	2%			
Frequency of shellfish consumption	1: Always; 2: Often; 3: Sometimes; 4: Rarely; 5: Never	2.952	0.73	1	5
Place of purchase of shellfish	Fisherman	8.0%			
Place of purchase of shellfish	Fish shop	57.0%			
Place of purchase of shellfish	Supermarket	20.0%			
Place of purchase of shellfish Hypermarket	Hypermarket	15.0%			
Place of purchase of shellfish	Other	0.0%			
Attention to product characteristics:	Place of purchase	3.27	0.89	1	5
Attention to product characteristics	Conservation method	3.42	0.79	1	5
Attention to product characteristics	Commercial species	3.24	0.77	1	5
Attention to product characteristics	Origin	3.23	0.86	1	5
Attention to product characteristics	Price	3.60	0.69	2	5
Do you know the blue crab?	Yes	67.50%			
Do you consume blue crab?	Yes	29.09%			
Reason for non-consumption	Dislike	5.91%			
Reason for non-consumption:	Allergy/intolerance	1.36%			
Reason for non-consumption	Cost	1.36%			
Reason for non-consumption	No-knowledge	43.64%			
Reason for non-consumption	difficulty of retrieval	9.32%			
How often do you buy blue crab?	1: Always; 2: Often; 3: Sometimes; 4: Rarely; 5: Never	1.37	0.67	1	5
Place of purchase of blue crab	Direct sale (fishermen)	12.27%			
Place of purchase of blue crab	Local fisheries markets	9.32%			
Place of purchase of blue crab	Supermarkets	2.50%			
Place of purchase of blue crab	Hypermarkets	5.00%			
Place of purchase of blue crab	Other	70.91%			
Place of consumption	Restaurant	7.50%			
Place of consumption	Events	3.64%			
Place of consumption	At home	17.27%			
Place of consumption	Other	71.59%			
Male	%	47%			
Female	%	53%			
Family members	Number	3.12	1.11	1	5
Education level	No education	0%			
Education level	Primary school	2%			
Education level	Secondary school	22%			
Education level	High school	38%			
Education level	University	37%			
Education (Total years of study)	Number	13.580	3.994	5	18
Gross household income	< EUR 25 000	23.6%			
Gross household income	≥ 25 000 EUR ≤ 50 000	55.5%			
Gross household income	> EUR 50 000	20.9%			

the consumer decisions. On the contrary, the preservation method ("fresh/chilled") and size ("large") coefficients were positive and highly significant for MNL and both groups of LCM models, as anticipated, indicating that these attributes provided Apulian consumers with great utility regarding, at least, the physical appearance of the seafood species. In addition, the signs for the attributes regarding the fishing origin ("Apulia Region") and the place of purchase ("fishermen" and "supermarket or hypermarket") were positive in general, reflecting the concerns of Apulian residents to keep or create local jobs and support local economies. They may also be more

Table 6. Multinomial Logit Model (MNL) and Latent Class Model (LCM) results.

Attribute	Multinomial Logit Model (MNL)		Latent Class Model (LCM)			
	100%		Class 1 (29.1%)		Class 2 (70.9%)	
	Coefficients					
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Seafood species ("Blue crab")	-0.279**	0.029	-1.931***	0.000	0.529***	0.000
Seafood species ("Spider crab")	-0.724***	0.000	-2.032***	0.000	-0.129	0.405
Preserving method ("Fresh")	1.217***	0.000	2.498***	0.000	1.128***	0.000
Preserving method ("Canned")	-0.804***	0.001	0.225	0.637	-1.130***	0.000
Size ("Large")	0.729***	0.000	1.212**	0.01	0.497***	0.000
Size ("Small")	-0.447***	0.004	-0.722*	0.093	-0.388***	0.003
Fishing origin ("Apulia Region")	0.195	0.187	0.208	0.5715	-0.142	0.277
Fishing origin ("Abroad")	-0.189	0.195	-0.047	0.891	-0.213*	0.092
Place of purchase ("Fishermen")	0.270*	0.080	0.114	0.725	0.274**	0.015
Place of purchase ("Supermarket/hypermarket")	0.129	0.322	0.136	0.737	0.636***	0.004
Price	-0.055***	0.000	-0.060**	0.031	-0.029***	0.000
Opt-out	-0.633***	0.009	0.207	0.706	-0.597**	0.013
Model statistics						
Criteria	MNL		LCM			
Log Likelihood	-2050		-1989			
Adjusted Akaike Information Criteria	4124		4028			
AIC/N	2.27		2.22			
Bayesian Information Criterion	4190.046		4165.753			
Number of observations	1815		1815			
Number of variables	12		25			

Note: ***, **, * ==> Significance at 1%, 5%, 10% level, respectively. The seafood species (pink shrimp) was the baseline in the econometric estimation results.

aware about the local fishing practices than those which are practised by overseas fisheries, as well as providing them with appreciated services in the supermarket or hypermarket in which a set of diversified seafood attributes is present. Furthermore, both classes of respondents had a negative price coefficient, but class 2 presented a higher intensity and highly significant coefficient, indicating that a small price variation might induce them not to purchase the product. In addition, the attribute related to the place of purchase ("fishermen") was appreciated by the respondents of the entire sample, since its coefficient had a positive value, but with different significance levels amongst the samples, thus verifying the hypothesis of heterogeneous consumer preferences for seafood species consumption. Moreover, the MNL results indicate a clear preference hierarchy: consumers prefer pink shrimp over blue crab and they like blue crab over spider crab. The preference for blue crab over spider crab indicates that, while blue crab may be less favoured than pink shrimp (used as a well-known widely consumed species), it is still viewed more favourably than spider crab (used to represent a quite similar alien species). The indirect implication of this hierarchy resides in the possibility that policy managers might implement regulations that promote responsible harvesting practices over other species and effective educational campaigns. Making consumers aware of the ecological impacts of blue crab invasions and the potential threats they pose to local ecosystems can influence their purchasing decisions. MNL per se does not tell us the characteristics of respondents but LCM does. It can be useful to address the mentioned educational campaigns based on the two classes characteristics.

Estimates of willingness to pay (WTP)

The WTPs (in EUR) estimation are reported in Table 7 and were obtained from positive and statistically significant LCM coefficients estimates (Table 4). As a result, the respondents of class 1 were not willing to pay a premium price for blue crabs and to consume as many as possible, in an attempt to manage the expansion of this invasive species in Italy. This result indicated the lack of sufficient awareness and information within this class of consumers about the potential benefits of the commercial exploitation of this aquatic invasive species as depicted in Fig. 2. On the contrary, respondents of the second class were willing to pay EUR 18.01 per kg on average for blue crabs' consumption, suggesting that the preferences of a representative part of Apulian residents would consume it, contributing to the control of the concerned non-indigenous aquatic species. Further, the respondents of this group were willing to pay more for the freshness attribute of seafood products, in which the related average WTP was estimated at EUR 33.06 per kg, indicating the relevance for fish stakeholders marketing several seafood products. Furthermore, the WTPs were positive, but relatively less for the size ("large") and place of purchase ("fishermen" or "supermarket/hypermarket"), compared to blue crabs' species and freshness attributes, suggesting these attributes to be considered as drivers for the consumption of the concerned seafood species. Finally, the preserving method ("fresh/chilled") presented the highest average WTP in both classes, in which this was estimated at EUR 46.38 and 33.06 per kg for respondents of class 1 and class 2, respectively, providing Apulian consumers with high utility or organoleptic satisfaction.

Discussion

Interpretation and comparison

The findings detailed in the Results section provide an understanding towards the perceptions and expectations of Apulian consumers, constituting one of the market drivers for any successful novel food product, such blue crabs (Kaimakoudi et al. 2013). In this regard, we applied a DCE approach to investigate the influence of the type of seafood species (i.e. blue crab, spider crab and pink shrimp), preserving/storage methods (i.e. fresh/chilled, frozen and canned), size (i.e. small, medium and large), fishing/capture origin (i.e. Apulia, Italy and abroad), as well as the selling price (i.e. EUR 10, EUR 17 and EUR 23 per kg versus the status quo or EUR 0) for each selected seafood species which may influence the consumers' preferences.

Table 7. Willingness to pay (WTP) estimates.

Class	Variable	WTP	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
1	Preserving method ("Fresh/chilled")	46.3819	190.7	0.24	0.8078	-327.38	420.147
	Size ("Large")	20.42	47.7826	0.43	0.6691	-73.232	114.072
2	Seafood species ("Blue crab")	18.0131	12.0209	1.5	0.134	-5.5474	41.5736
	Preserving method ("Fresh/chilled")	33.0611	16.5714	2	0.046	0.5818	65.5404
	Size ("Large")	16.1509	8.6523	1.87	0.0619	-0.8073	33.1091
	Place of purchase ("Fishermen")	8.38602	5.77782	1.45	0.1467	-2.9383	19.7103
	Place of purchase ("Supermarket or hypermarket")	10.0112	6.29548	1.59	0.1118	-2.3277	22.3501

As a result, we found that most Apulian inhabitants (around 70% of the whole sample) were not opposed to introduce the blue crabs into their nutritional diet/food system and were willing to pay a positive average amount of EUR 18.01 per kg for blue crabs, prompting fishermen and retailers to adjust their pricing strategies accordingly in line with consumer expectations and maximize revenues. In fact, we observed that the retail market price at which a blue crab was sold to consumers, oscillated between EUR 8 to 12 per Kg at most supermarkets across Apulia region during 2023. This price is normally influenced by several factors including production costs, competition, demand and market conditions. As such, the blue crabs, which have a market value of around €80 a kilogram in the United States and Asia, appear not to be able presently to fetch much on the Italian market. However, the findings in terms of WTP differ by social class membership and type of attributes. In fact, the Apulian inhabitants gain higher utility for the preserving method ("fresh/chilled") and size ("large") attributes, but, for the place of purchase ("direct purchase or supermarket/hypermarket"), respondents of class 2 expressed relatively lower WTPs, indicating that the freshness attribute appears here to be a determinant driver for Apulian inhabitants' consumption of seafood species, such blue crabs. Moreover, the MNL results indicate a clear preference hierarchy: consumers prefer pink shrimp over blue crab and they like blue crab over spider crab. The preference for blue crab over spider crab indicates that, while blue crab may be less favoured than pink shrimp (used as a well-known widely consumed species), it is still viewed more favourably than spider crab (used as a quite similar alien species). The indirect implication of this hierarchy resides in the possibility that policy managers might implement regulations that promote responsible harvesting practices over other species and effective educational campaigns. Making consumers aware of the ecological impacts of blue crab invasions and the potential threats they pose to local ecosystems can influence their purchasing decisions. MNL per se does not tell us the characteristics of respondents, but LCM does. It can be useful to address the mentioned educational campaigns, based on the two classes characteristics. Furthermore, the findings illustrate significant differences between the two classes of the studied population for most of the variables related to the purchasing habits and propensities of Apulia residents towards fish products, their knowledge of the blue crabs, as well as their socio-economic profile. With respect to "Class 1", this respondents' segment had higher food purchase frequencies, but relatively lower shellfish consumption. In addition, this class had a higher percentage of respondents with low income and a higher number of household members. Moreover, in this group, the knowledge of blue crab was higher and we observed the largest number of people who cited taste and the presence of allergies as reasons for non-consumption. Regarding "Class 2", these respondents consumed shellfish in general and blue crabs more frequently than the first group. The attention to the price of products was higher and the highest percentage of purchases was directly from the fisherman. In this segment, respondents had higher educational level and male respondents were older than in Class 1 as observed in Table 8. Consequently, our findings are consistent with a recent EU consumer study on habits regarding fishery and aquaculture products in Italy (European Union 2021), as well as with previous similar studies in the Euro-Mediterranean Basin. For example, Minasidis et al. (2023) stated that Greek consumers would buy and consume non-indigenous fish species, in which the freshness was ranked as the most important factor for the purchase of this marine species. Moutopoulos et al. (2022) observed that consumers' attitudes towards the consumption

of Pearl oyster (*Pinctada imbricata radiata*) differ according to their socio-economic profile, in which highly-educated consumers were more willing to purchase and consume this kind of marine species. Additionally, Cerveira et al. (2022) found that Portuguese consumers were willing to consume another edible aquatic invasive species, the Weakfish *Cynosian regalis* (Bloch & Schneider, 1801). In addition, Marchessaux et al. (2023) reported that 58% (33% in Italy) have already consumed and appreciated both blue crab species. However, our findings are in line with Petrontino et al. (2022) who also reflected on the importance of the geographic or fishing origin as the seafood consumption driver. Lastly, Grover et al. (2021) found that Australian households were willing to pay $AUD 37 per year for 5 years for the management of native and invasive species in coastal waters off the east coast of Tasmania.

Table 8. Comparison between the two classes of the studied population, for the purchasing habits and propensities towards fish products, their knowledge of the blue crabs, as well as their socio-economic profile.

Variable	Category	Mean or %		p^*
		Class 1	Class 2	
Frequency of food purchase	1: Once a day; 2: More than once a week; 3: Once a week; 4: More than once a month; 5: Once a month; 6: Less than once a month; 7: Never	6.097	5.858	< 0.001
Frequency of shellfish consumption	1: Always; 2: Often; 3: Sometimes; 4: Rarely; 5: Never	2.922	3.015	< 0.001
Attention to product characteristics	Place of purchase	3.32	3.288	0.177
Attention to product characteristics	Conservation method	3.495	3.446	0.018
Attention to product characteristics	Commercial species	3.223	3.285	0.003
Attention to product characteristics	Origin	3.194	3.254	0.008
Attention to product characteristics	Price	3.544	3.608	< 0.001
Do you know the blue crab?	Yes	1.427	1.258	< 0.001
Do you consume blue crab?	Yes	1.748	1.665	< 0.001
Reason for non-consumption	Dislike	0.087	0.054	< 0.001
Reason for non-consumption	Allergy/intolerance	0.039	0.004	< 0.001
Reason for non-consumption	Price	0.01	0.008	0.393
Reason for non-consumption	Lack of knowledge	0.417	0.435	0.184
Reason for non-consumption	Difficulty of retrieval	0.078	0.077	0.914
How often do you buy blue crabs?	1: Always; 2: Often; 3: Sometimes; 4: Rarely; 5: Never	1.272	1.446	< 0.001
Blue crab's satisfaction (index of evaluation)	Scale of 1 to 10	7.37	7.573	0.017
Age	Year	52.214	54.931	< 0.001
Gender	Female	0.398	0.442	< 0.001
Family members	Number	3.146	3.004	< 0.001
Education	Total number of studies	13.718	13.746	0.784
Gross household income	< EUR 25 000	0.272	0.223	< 0.001
Gross household income	≥ 25 000 EUR ≤ 50 000	0.534	0.573	0.002
Gross household income	> EUR 50 000	0.194	0.204	0.354
Place of purchase of blue crab	Direct sale (fishermen)	2%	11%	(baseline)
Place of purchase of blue crab	Local fisheries markets	2%	7%	< 0.001
Place of purchase of blue crab	Supermarkets	1%	2%	0.505
Place of purchase of blue crab	Hypermarkets	1%	4%	< 0.001
Place of purchase of blue crab	Other	21%	47%	< 0.001
Place of consumption	Restaurant	2%	6%	(baseline)
Place of consumption	Events	1%	3%	0.011
Place of consumption	At home	4%	14%	0.127
Place of consumption	Other	21%	48%	< 0.001
Education level	Primary school	1%	1%	(baseline)
Education level	Secondary school	6%	16%	< 0.001
Education level	High school	11%	28%	< 0.001
Education level	University	11%	27%	< 0.001

Limitations and future research directions

The first limitation of this research includes its regional level coverage. Future DCE studies should counter this issue by selecting a national representative sample to explore potential insights into Italian regional differences and communities in attitudes and propensity to purchase and consume blue crabs. A second limitation is related to the use of two criteria (age and gender) to the sampling method adopted. However, follow-up studies should include the annual revenues of participants in the survey and their residence, reflecting their culture and traditions (Sacchettini et al. 2021) and inducing a better representation of Italian consumers towards their social perception and WTPs to control the *Callinectes sapidus* invasion in Italy. A third limitation of this study considers the "general public" as participants/respondents in our DCE approach, excluding other key fish stakeholders that may present a greater preferences utility for consumption of blue crabs. As such, we may suggest an extension on examining the interest utility amongst other groups of respondents to cover the preferences of tourists and ethnicity (Sayeed et al. 2022) and of local fish entrepreneurs or other groups of stakeholders (i.e. fishermen, seafood species processors, retailers, consumer organisations) for whom the human consumption of this biological invader would become a sustainable effective management tool, inducing positive impacts on their income and enhancing their financial performance. Here, it would be beneficial to conduct further research, based on a cost-benefit analysis (Courtois 2004; Courtois et al. 2014; Rajmis et al. 2016; Frem et al. 2022) allowing us to: (*i*) assess the impacts on commercial shellfish fisheries, (*ii*) estimate the costs of this blue crab invasion, (*iii*) justify its public management expenditure (Falk-Petersen and Armstrong 2013) and identify the maximum economic yield, preventing potential losses from overharvesting practice. Additionally, bio-economic modelling (McDermott et al. 2013; Varble and Secchi 2013; Benjamin and McDermott 2018) should be addressed in the future to explore how this potential commercial exploitation (Kourantidou and Kaiser 2021b) of the blue crab would really help to manage its invasiveness, taking into consideration two possible scenarios: (i) minimising its population pressure at the lowest possible level, while protecting adult females and critical nursery habitats like underwater grasses which are crucial for future crab numbers and (ii) allowing a sustainable level of catches for fishermen (i.e. to stabilise a certain level of biomass of the invasive alien species, maintaining a balance where catches do not exceed sustainable levels) across several Italian seas. In this line, Italian governmental efforts are being made to manage the blue crab invasion through resource allocation to fishermen. Allowing a commercial fishery for human consumption will increase fishermen's income, but might not ensure sustainable exploitation (Nardelli et al. 2024). According to EBFM (2010), the strengths of blue crabs' exploitation include: (i) Economic value (i.e. blue crabs may provide livelihood and income for many fishermen. The fishery supports local fishermen's' income and a potentially significant processing sector for crabmeat production, contributing to the local economy); (ii) Recreational fishery for blue crabs also supports a major recreational fishery, providing potential opportunities for recreational fishermen to enjoy crabbing activities; and (iii) Market demand; i.e. blue crabs appear to be in demand in both commercial and recreational sectors, with a variety of markets for fresh, frozen or processed crab. However, the blue crab exploitation also has weaknesses in terms of: (i) Vulnerability to overexploitation (i.e. blue crabs are

susceptible to overexploitation due to their economic importance, which can lead to population declines if not managed sustainably); (ii) Habitat degradation (i.e. fishing pressure can impact living habitats for blue crabs, such as salt marshes, leading to alterations in trophic interactions and potential habitat loss as stressed in the Introduction section); (iii) Environmental stressors (i.e. factors like climate change, habitat degradation and pollution can affect blue crab populations and their habitats, making them more vulnerable to exploitation) and (iv) competition with imports (i.e. globalisation of seafood markets has led to competition with imported crab products, affecting the market for local blue crabs and putting pressure on domestic fishermen). The blue crab exploitation may also include opportunities such as: (i) Sustainable management practices (i.e. implementing sustainable fisheries management practices can help ensure the long-term viability of blue crab populations and the fishery); (ii) Market diversification (i.e. exploring new markets and value-added or elaborated products can help diversify the market for blue crabs and assure further economic opportunities for fishermen); and (iv) Ecosystem health (i.e. blue crabs may play a significant role in the affected Italian lagoon ecosystem and their sustainable exploitation can contribute to ecosystem health and balance).

Furthermore, as the blue crab has usually been identified as a bioindicator organism of polychlorinated biphenyls, polycyclic aromatic hydrocarbons and methyl mercury (Ghaeni et al. 2015), as well as source pollutants for trace elements contamination (Cubedo et al. 2018; Salvat-Leal et al. 2020), we may also recommend the exploration of the acceptance of the adoption by respondents of the block-chain traceability system within the blue crabs value chain. This would mainly be applied for fishing activities and conservation methods as an innovative digital tracking tool for this kind of aquatic invader, which may influence positively or negatively, as well as significantly, their potential purchase decision. Lastly, the present choice experiment model could be enhanced by involving other specific blue crabs attributes related, but not limited to: (i) the level (greater or lesser) of blue crab's impacts on the ecosystem, on other economic sectors and on propagation in which the DCE may capture this crucial information related to invasive species management; (ii) the level or types of fisheries, such as small-scale units for development and industrialisation; (iii) the integration of blue crabs on to restaurants menus; (iv) the improvement of local food diet, in which the blue crabs present a high nutritional value, the social aspect in terms of creation or increase in local employment and public and private communication, research and management activities towards biological coastal invasion.

Conclusion

The present paper reveals the existence of two blue crab's consumer segments, reflecting a potential market for an edible marine invasive species. By capitalising on its exploitation opportunities as addressed above, stakeholders should work towards sustainable blue crab exploitation that benefits both the environment and Italian local economies. Thus, sustainable management practices, habitat conservation efforts and market strategies would be crucial to safeguarding the long-term health and sustainability of blue crab populations in the study area, in line with EU REG 1380/2013. In addition, the implemented DCE approach provides, in this paper, estimates through the estimation of WTPs that are useful in making private deci-

sion or public policy support. In this direction, one of the most significant findings of this study is that an important part of the Apulian inhabitants' sample (70%) expressed their interest towards the consumption of blue crabs and, consequently, to potential commercial exploitation of blue crabs as a novel food source. As such, this result provides a first good preliminary insight for fish entrepreneurs and restaurants to integrate this novel food into their shops and menus, respectively. In this direction, the development of this kind of novel food business requires raising public awareness through policy-makers and educational institutions and communication about its consumption benefits, to target mainly the segment of consumers who were not willing to pay a premium price towards the blue crabs' consumption in Italy. This could also probably lead to a change in their intentions and perceptions, making them more responsible and predisposed to buy edible aquatic invasive species. In addition, the adoption of a suitable targeted marketing strategy by the firms or fishery cooperatives involved in the catches of fish would reinforce the image of this aquatic invader, promoting its sustainable consumption in the near future.

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Additional information

Conflict of interest

Michel Frem was employed by Sinagri S.r.l. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical statement

The data gathered from the in-person survey was solely utilised for statistical analysis and the specific research project. According to Regulation (EU) 2016/679, personal data will not be shared with third parties or used for personal interests, whether one's own or others. The information obtained was solely utilised in a collective manner, ensuring the utmost anonymity of the participant. Additionally, respondents were asked for their consent at the start of the survey to take part in this research in line with national laws and institutional rules.

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Author contributions

Michel Frem: Writing – original draft, Writing – review & editing, Conceptualisation, Methodology, Formal data analysis, Supervision, Validation and Visualisation. Ludovica Nardelli: Writing – review & editing, Data collection. Alessandro Petrontino: Writing – review & editing, Conceptualisation, Methodology, Formal data analysis. Ståle Navrud: Writing – review & editing and Validation. Maria Antonietta Colonna: Writing – review & editing. Vincenzo Fucilli: Writing – review & editing, Funding acquisition, Supervision and Validation. Francesco Bozzo: Writing – review & editing, Funding acquisition and Validation.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Appendix 1

Marine fishing overview of the study area

The Apulian fleet has a strong social and economic dependence on artisanal fishing. According to the National Statistics Institute the fishing fleet in the study area is composed of 1629 vessels distributed amongst the seven maritime Compartments of this region: the Manfredonia Compartment possesses the highest number of boats (31.43%), followed by Gallipoli (22.28%), Bari (17.31%), Barletta (9.21%) and Brindisi (5.89%) in 2020. However, the Molfetta Compartment has the lowest number of boats (3.38%). The overall production of the Apulian fleet is around 7000 tonnes, of which 75.87% are captured through the otter trawling technique followed by fixed longlines (9.79%), anchored gillnets (4.00%), dredgers pulled by boats (2.50%) and purse seine (1.13%). In 2020, the catches per unit were equal to 4208 kg. With respect to the importance of the different fishing methods in Apulia, the significant volume of 5.2 tonnes relating to the "trawling with divergent" technique (75.87%) reflects the highly heterogeneous character of Apulia fishing. However, the two fishing techniques, "gillnets (drift) and beam trawling", are not practical in this Region. Furthermore, the "hand-line" technique is used in a very limited manner for catching fish in the study area. In addition, Apulia has a total tonnage of 18,500 GT and an engine power of 122,234 kW, of which the fishing technique with an otter trawl has the highest percentage in terms of tonnage (71.71%), followed by the techniques of: purse seine (12.71% in GT), fixed longlines (8.16% in GT), dredgers pulled by boats (4.41%) and anchored gillnets (2.45%). The average size of a boat in Apulia is 11.4 tonnes, compared to a national average of 14.2 tonnes in 2020.

Appendix 2

Italian financial aid to encounter the spread of the blue crabs: a summary

The rules governing the production and trade of fishery and aquaculture products marketed in Italy fall under EU's Common Market Organisation in Fishery and Aquaculture Products (CMO) Regulation, which is one of the pillars of EU's Common Fishery Policy. Consequently, the sale of the blue crab is currently not prevented by the CMO regulation, meaning that the consumption and even marketing of this crustaceous, not currently on the list of invasive alien species (IAS) of community interest, does not go against the EU's policy of managing the market for fishery and aquaculture products (European Union regulation 2013 available at https://eur-lex.europa.eu). Moreover, in the case that the blue crab is included in this list later, it would be subject to numerous restrictions under Article 7 of IAS EU Regulation and consequently, could not be placed on the market, stored, used or traded. However, another article of the IAS Regulation says that the commercial use of already established IAS may be temporarily permitted, but only as part of management measures aimed at their eradication, control or containment of the population. Meanwhile, to counter the spread of the blue crab species (*Callinectes sapidus* and *Portunus segnis*) throughout the Italian national territory and prevent the aggravation of

the damage inflicted to the economy of the fishing sector, the Italian Ministry of Agriculture (*Ministro dell'agricoltura, della sovranità alimentare e delle foreste*, hereafter MASAF) released a decree law of 10 August 2023, in which article 10 authorised the expenditure of EUR 2,900,000.00 in favour of the aquaculture and fisheries companies that catch and dispose of the aquatic species mentioned above.

This Ministerial Decree (MASAF 2023) defined all eligible costs incurred for measures taken to catch and dispose of blue crabs, in particular: (1) costs for the catch (i.e. purchase of fishing gear specially used for catching blue crabs, such as pots, gillnets and cages, containment nets), (ii) costs for disposal (i.e. costs incurred in the disposal of blue crabs as waste at Italian establishments approved or registered under Reg. (EC) 1069/2009 in respect of animal by-products listed by the Ministry of Health - Directorate-General for Food Hygiene and Food Safety and Nutrition and transport costs of blue crabs to facilities authorised for disposal, such as forklift hire, cold storage hire, waste containers, plastic boxes, bins). Only expenditure incurred from 1 August 2023 until 31 October 2023 was eligible. However, the purchase of towed fishing gear was not eligible for the contribution. Moreover, the grant is provided in the form of a non-repayable contribution to the extent of 80% of the costs actually incurred in relation to the eligible interventions. Moreover, the contributions referred to in this Decree may be accumulated with any other State aid in relation to the same wholly or partly overlapping eligible costs, only where such accumulation does not lead to the highest aid intensity or aid amount applicable to the type of aid concerned being exceeded. In addition, the territorial competent Marine Authorities were assigned the tasks of control regarding the requirements previewed from the present Decree that can happen also after the distribution of the contribution. To the correct accomplishment of the controls, the Ministry puts at the disposal of the Maritime Authorities in a timely manner all the documentation produced by the applicants for the purposes of obtaining the contributions referred to in this Decree.

Supplementary material 1

Experimental design

Author: Michel Frem

Data type: xlsx

Explanation note: Statistical experimental design of the research: Discret choice experiment.

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Link: https://doi.org/10.3897/neobiota.96.123885.suppl1

Supplementary material 2

Surevy questionnaire

Author: Michel Frem

Data type: docx

Explanation note: Social survey used in this research based on the Discrete choice experiment approach.

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